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MAG

US – LHC Collaboration

1.1.4 - TAS Absorbers

Thermal FEA Analyses of the TAS Subject to Ultimate Luminosity and Bake Out

A. SUMMARY

The analyses described in this document have been carried out as a validation of the initial hand calculations detailed in Engineering Notes M7747A, M7800 and M7801. An ANSYS thermal finite element model of the LHC TAS Absorber was constructed in order to analyze two different operating conditions. The first analysis calculates the steady-state temperature distribution within the TAS subject to an ultimate luminosity heat load of 400 watts during beam operation. The second case is a transient analysis representing an in-situ bake-out of the TAS with a total continuous heat load of 6000 watts supplied by four embedded heaters. In both cases, the heat is removed from the system only by means of free convection and radiation at the exposed surfaces. The calculated temperature history of the vacuum chamber for the bake-out case is compared to that measured with a thermocouple during the initial testing of the actual system.

B. MODEL DETAILS

The TAS model was constructed using axisymmetric ring elements with a three-dimensional thermal conduction capability. The element has four nodes with a single degree of freedom, temperature, at each node. The element is applicable to a two-dimensional, axisymmetric, steady-state or transient thermal analysis. An ambient air temperature of 20 °C is assumed. Figure 1 shows the overall model geometry.

The analysis is complicated by the fact that there are air-gaps present between several of the system components. The beam tube is separated by .25 mm from the copper absorber, there is a 21 mm gap between the copper and the iron nose shielding and a 55 mm gap between the iron and the concrete shielding. The heat transfer across the air gaps occurs through a combination of conduction, free convection and radiation.

Since this type of problem cannot be modeled directly using ANSYS, a series of spreadsheet calculations were performed to determine effective thermal conductivities for the air gaps. The resulting temperature dependent conductivity curve combines the effects of conduction, convection and radiation based on the wall temperatures at either side of the air gaps. Since the wall temperatures are initially unknown, the final solution is obtained after several iterations. Heat is transferred to the environment from the exterior surfaces of the TAS by means of both free convection and radiation. This effect is modeled by computing a temperature dependent convection coefficient that is applied to the outer surfaces. In all cases, the appropriate factors are calculated based on textbook formulae [2] for free convection and radiation.

C. STEADY-STATE BEAM LOADING RESULTS

The steady-state beam loading is represented by a uniform heat flux totaling 400 watts on the front surface of the 240 mm diameter beam tube flange. As previously stated, heat removal is achieved only through radiation and free convection to the surrounding ambient air. The resulting temperature distribution for the entire TAS is shown in Figure 2. The elements representing the air gaps have been removed for clarity. As expected, the front surface of the flange reaches the highest temperature (86 °C). The beam tube temperature is approximately 55 °C. Figure 3 shows temperature contour in only the copper absorber with a range from 50 to 56 °C. The temperature contour in the iron, concrete and polyethylene are plotted separately in Figure 4. The iron is at approximately 30 °C with the balance of the temperature drop occurring across the concrete and polyethylene.

D. TRANSIENT BAKE-OUT RESULTS

The transient bake-out heat loading is represented by volumetric heating throughout a 13 mm thick zone on the outer diameter of the copper absorber totaling 6000 watts. The complete time-history analysis consists of a 27 hour heating period followed by a 24 hour hold and a 96 hour cool down. The temperature contour for the entire TAS at the end of the 27 hour heating cycle is shown in Figure 5. Again, the elements representing the air gaps are not shown. As can be seen in the figure, the beam tube and copper absorber reach temperatures in the 200 °C range while the steel and concrete/polyethylene shielding remains at 60 °C or less. The temperature contour in only the beam tube and copper are shown in Figure 6. Note that all portions of the inner wall of the beam tube have reached at least 200 °C at the end of the heating cycle.

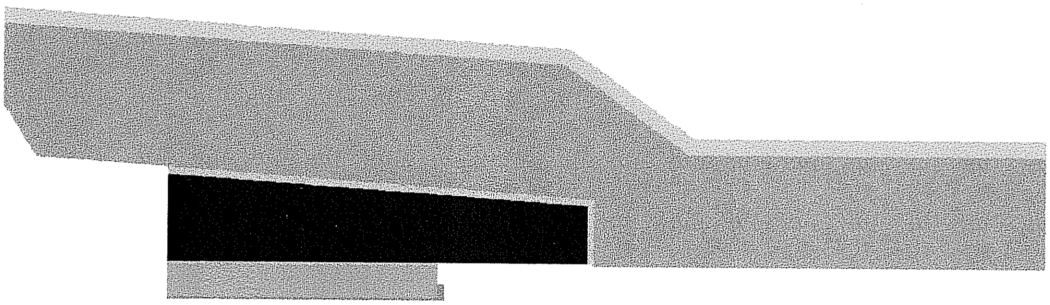
The transient temperature histories at several locations in the TAS are plotted in Figure7. The curve labeled "Flange" represents a point on the outer edge of the beam tube flange, and the "Tube" curve is the temperature of the inside beam tube wall near the center. The "Steel" curve shows the temperature history in the iron nose shielding at a point on the surface immediately across the air gap from the copper. As seen in the figure, all components have reached a temperature of 40 °C or less after 96 hours of cooling.

Some initial data has been recorded during the heater testing on one of the actual TAS absorbers. Te relevant data consists of a temperature history for the beam tube during a 9 hour heating period where the temperature was raised from ambient to 140 °C. The system did not include the iron, concrete or polyethylene portions of the TAS. Figure 8 shows the measured temperature profile overlayed with the predicted 27 hour heating profile. The two curves agree to within 5%. The measured temperature is slightly lower because more heat is lost directly to the air without the presence of the shielding.

E. REFERENCES

[1] ANSYS Finite Element Analysis Code, Release 5.7, ANSYS Inc., Canonsburg, PA.

[2] Heat Transfer, 5th Edition, J. P. Holman, McGraw-Hill, 1981.



Blue: beam tube
Black: iron nose shielding
Green: polyethylene jacket
Orange: copper absorber
Dark gray: concrete shielding
Light gray: air gaps

Figure 1. Overall TAS Axisymmetric Model Geometry

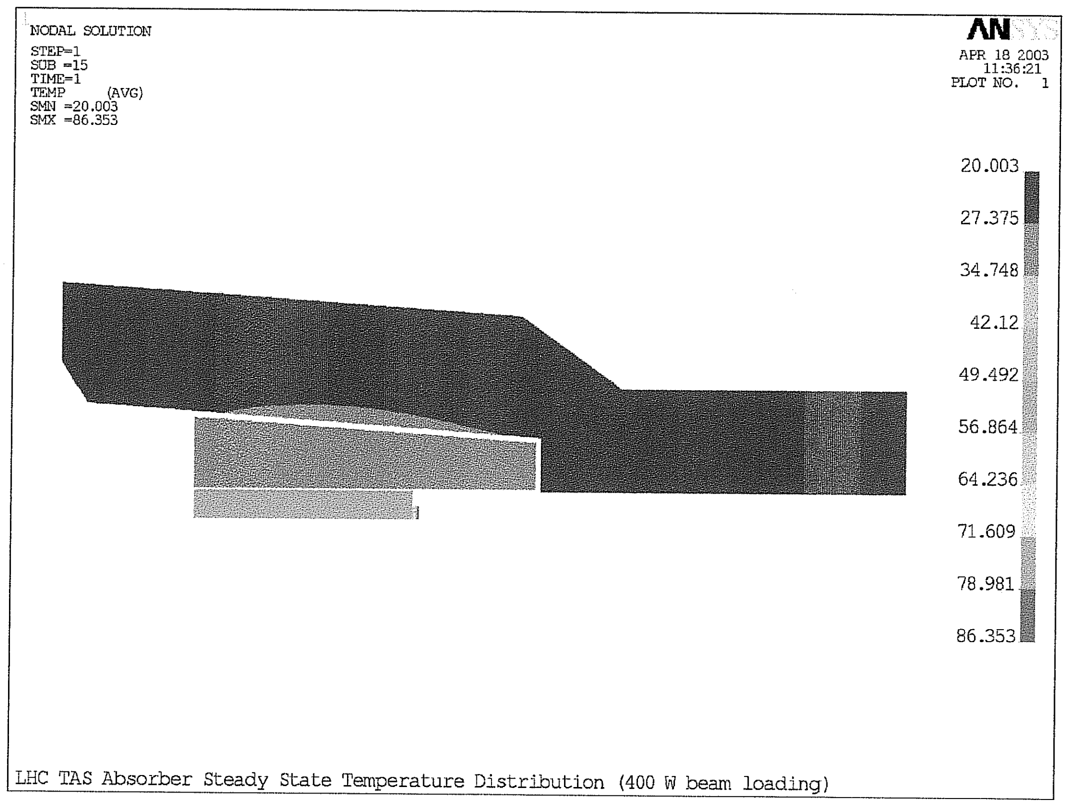


Figure 2. Steady-state Temperature Distribution in the TAS

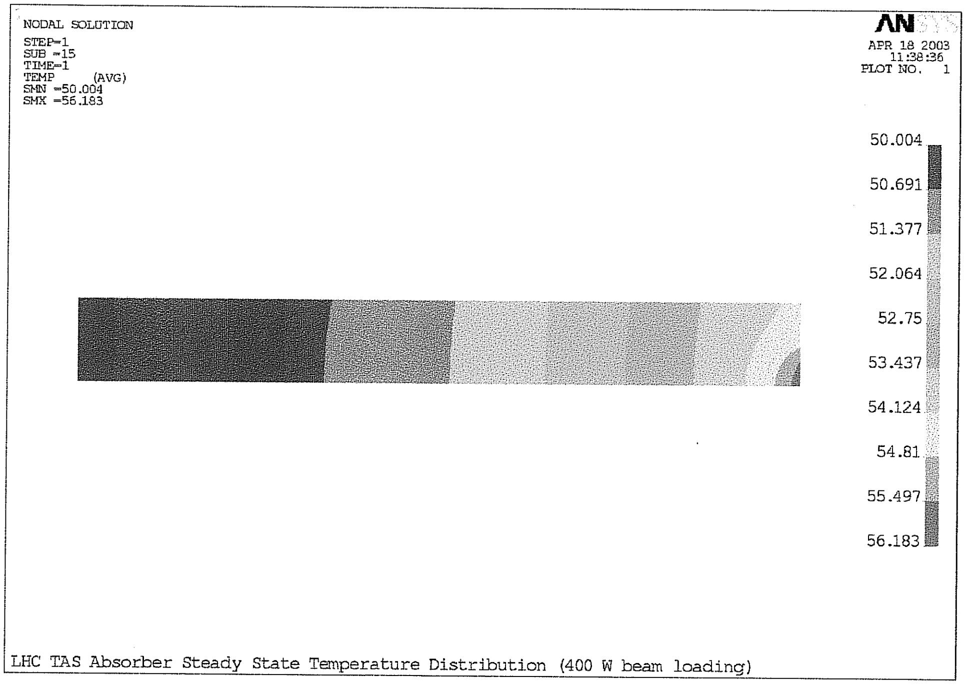


Figure 3. Steady-state Temperature Distribution in the TAS Copper Absorber

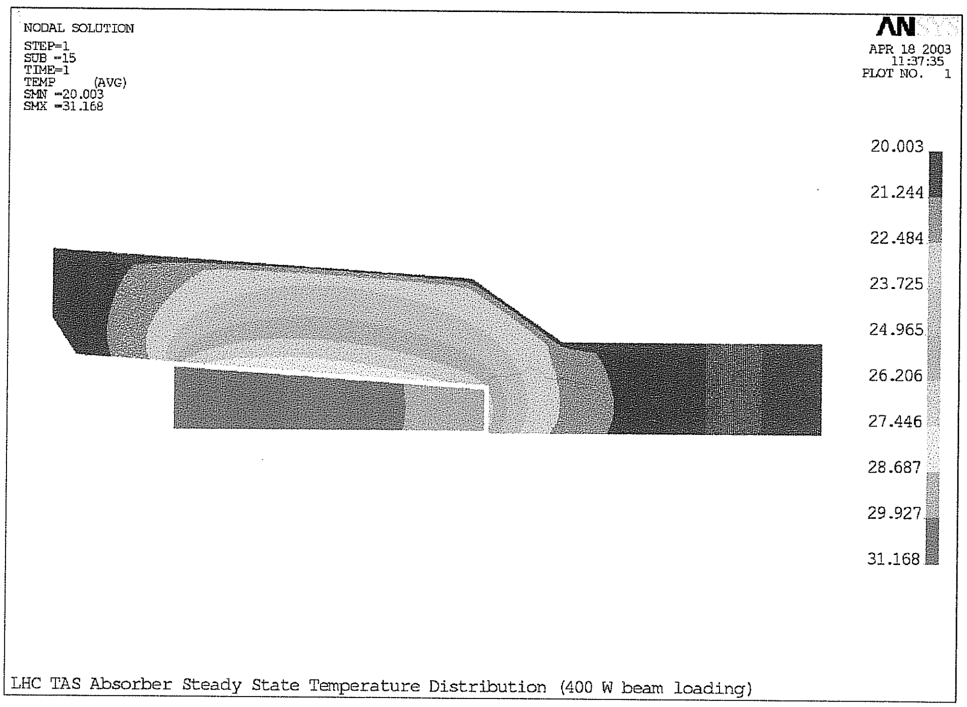


Figure 4. Steady-state Temperature Distribution in the TAS Shielding

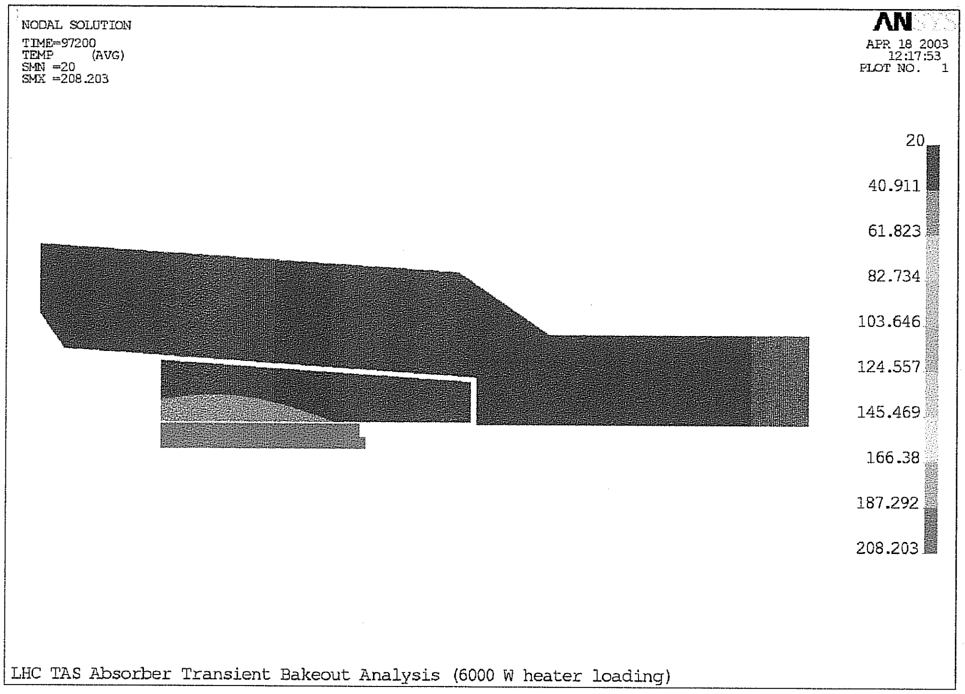


Figure 5. Temperature Distribution in the TAS after 27 Hours of Heating

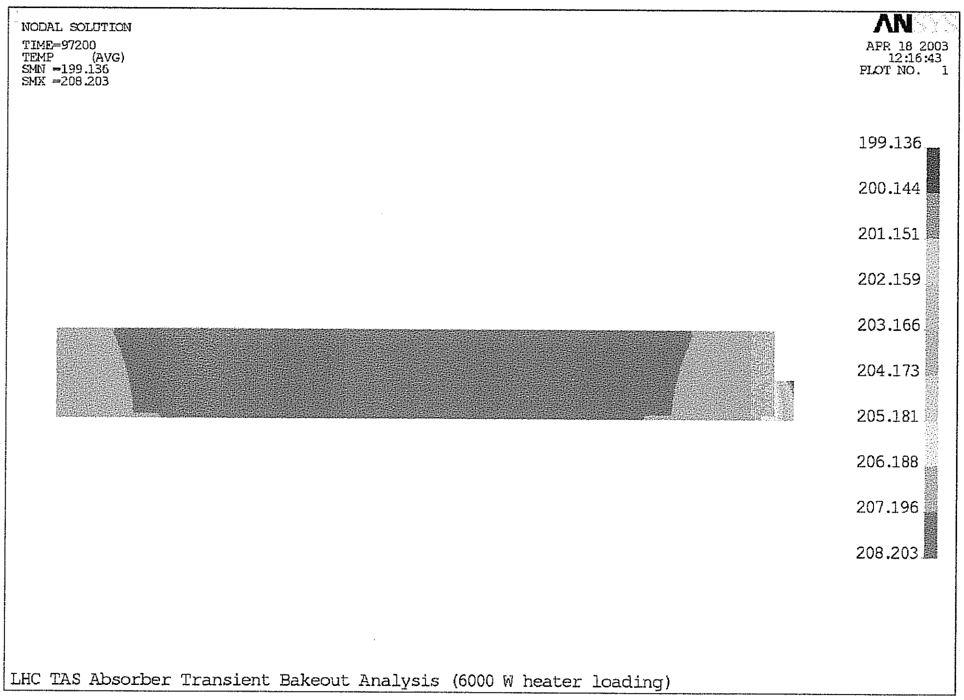


Figure 6. Temperature Distribution in the Absorber and Beam Tube after 27 Hours

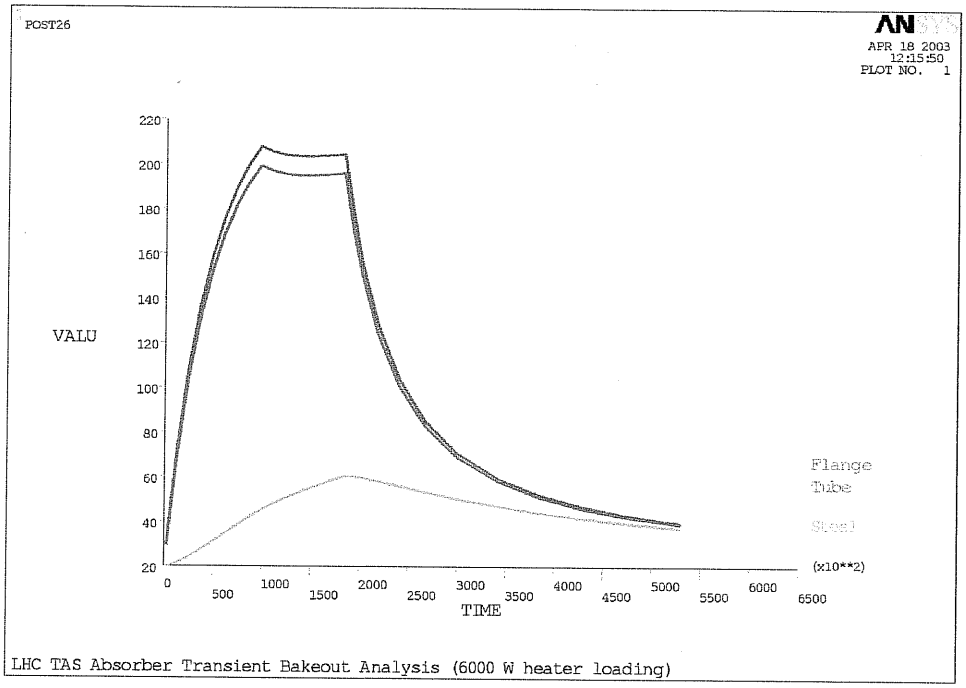


Figure 7. Bake-out Temperature History of Several Locations in TAS

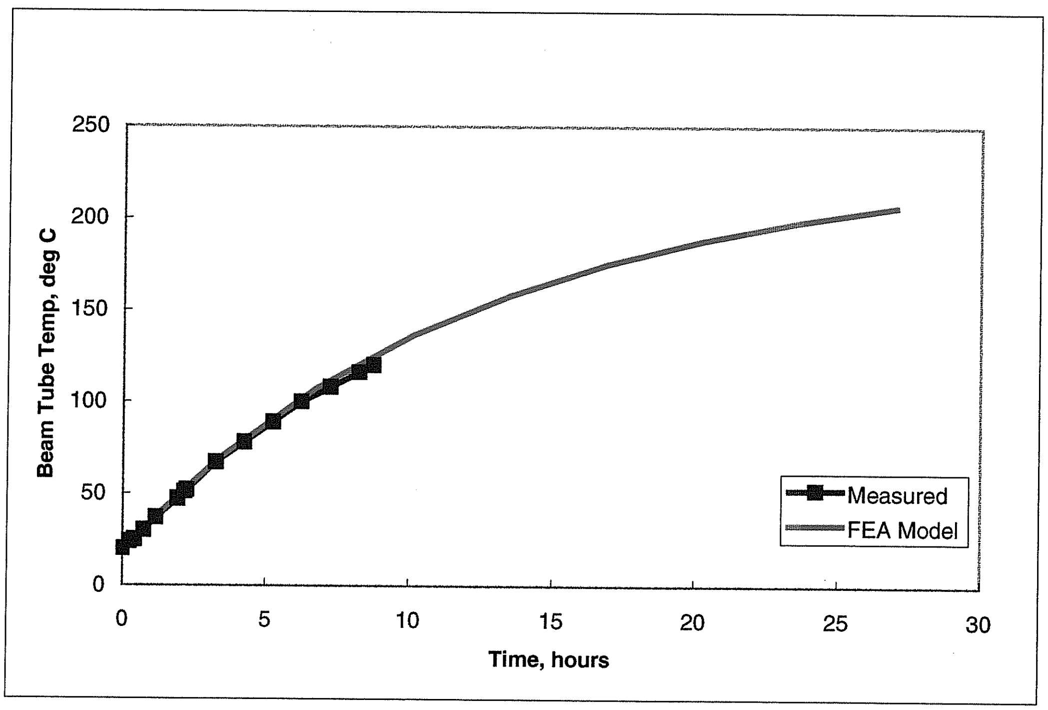


Figure 8. Predicted and Measured Beam Tube Temperature Histories